Mech 212 – Finned Cooling

Assignment Questions

Question 1 & 2

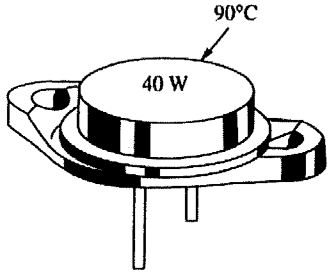


FIGURE P8-143

8-142 The case-to-ambient thermal resistance of a power transistor that has a maximum power rating of 15 W is given as 25°C/W. If the case temperature of the transistor is not to exceed 80°C, determine the power at which this transistor can be operated safely in an environment at 30°C.

8-143 A 40-W power transistor is to be cooled by attaching it to one of the commercially available heat sinks shown in Table 8-6. Select a heat sink that will allow the case temperature of the transistor not to exceed 90°C in the ambient air at 20°C.

Question 3

8-150 A hot surface at 100°C is to be cooled by attaching 3-cm-long, 0.25-cm-diameter aluminum pin fins [$k = 237\ \text{W/(m}\cdot{}^\circ\text{C)}$] to it, with a center-to-center distance of 0·6 cm. The temperature of the surrounding medium is 30°C, and the heat transfer coefficient on the surfaces is $35\ \text{W/(m}^2\cdot{}^\circ\text{C)}$. Determine the rate of heat transfer from the surface for a 1 m × 1 m section of the plate. Also determine the overall effectiveness of the fins.

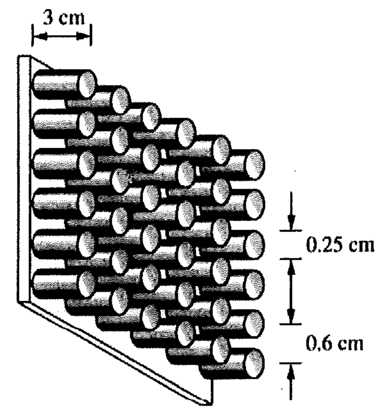


FIGURE P8-150

Question 4

A 0.3 cm thick, 12 cm high and 18 cm long circuit board houses 80 closely spaced logic chips on one side. Each chip dissipates 0.04 W. The board is impregnated with copper fillings, and has an effective thermal conductivity of 20 W/m-°C. All the heat generated in the chips is conducted across the circuit board and is dissipated from the back side of the board to the medium at 40°C with a heat transfer coefficient of 50 W/m^2-°C.

Determine:

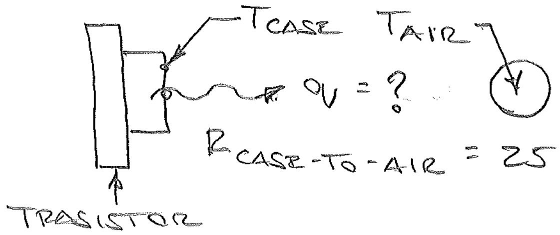
a. the temperatures on the two sides of the circuit board (chip side and cooling medium side).

b. In an attempt to improve the heat transfer characteristics of the board/chip system, a 0.2 cm thick, 12 cm high and 18 cm long aluminium plate (k = 237 W/m-°C) with 864, 2 cm long aluminium pin fins of diameter 0.25 cm is attached to the back side of the circuit board with a 0.02 cm thick epoxy adhesive (k = 1.8 W/m-°C).

Now determine the temperatures on the two sides of the circuit board.

MECH 212 - FINNED COOLING ASSIGNMENT SOLUTIONS

QUESTION 1 (8-142).



$R_{CASE\text{-}TO\text{-}AIR} = 25\ °C/W$

RECALL: $q = \dfrac{T_{CASE} - T_{\infty}}{R_{CASE\text{-}TO\text{-}AIR}}$

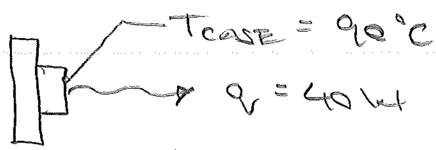
$T_{CASE} = 80\ °C$

$T_{AIR} = 30\ °C$

$\therefore\ q = \dfrac{(80 - 30)}{25}, \dfrac{°C}{°C/W}$

$\boxed{q = 2 \text{ WATTS}}$

QUESTION 2 (8-143)



$T_{AIR} = 20\ °C$

$R_{CASE\ TO\ AIR} = ?$

FROM $q = \dfrac{T_{CASE} - T_{\infty}}{R_{CASE\text{-}TO\text{-}AIR}}$

$R = \dfrac{T_{CASE} - T_{\infty}}{q}$

$= \dfrac{(90 - 20)}{40}, \dfrac{°C}{W}$

$R = 1.75\ °C/W$

FOR THIS TO WORK R MUST BE LESS THAN 1.75 °C/W

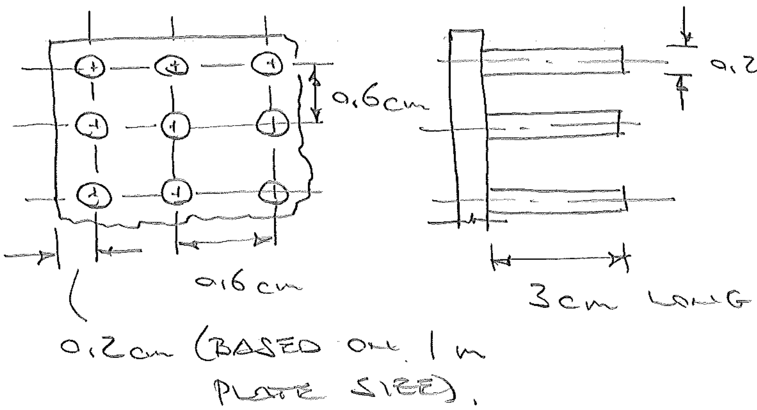
FROM TABLE 8-6 (SEE WEB PAGE).

- HS5030 R = 0.9 °C/W (VERTICAL)
- HS5030 R = 1.2 °C/W (HORIZONTAL)
- HS6071 R = 1.4 °C/W (VERTICAL).
- HS6115 R = 1.1 °C/W (VERTICAL).
- HS6115 R = 1.3 °C/W (HORIZONTAL).

ALL THESE ARE OK.
MAKE A FINAL SELECTION BASED ON SIZE AND OTHER FACTORS.

QUESTION 3 (8-150)

- FIND q FOR A 1 m X 1 m PINNED PLATE.
- NUMBER OF PINS = n = 166 × 166 = 27556 PINS (166/SIDE).



- CALCULATIONS

$k = 237\ W/m \cdot C$ $\quad T_\infty = 30\,°C$ $\quad \therefore \theta_b = 100 - 30$

$h = 35\ W/m^2 \cdot C$ $\quad T_{SURFACE} = T_s = 100\,°C$ $\quad \theta_b = 70\,°C$

RECALL $q = h(A_b + \eta_f A_f)\theta_b$

$A_b = A_{base} - A_{fin\ base}$

$= (1\,m \times 1\,m) - (27556)\left(\frac{\pi(0.25\times10^{-2}\,m)^2}{4}\right)$

$A_b = 0.865\ m^2$

$A_f = (27556)\left[\left(\pi(0.25\times10^{-2}m)(3\times10^{-2}m)\right) + \left(\frac{\pi(0.25\times10^{-2})^2}{4}\right)\right]$

SIDES — END.

$A_f = 6.63\ m^2 \quad (0.241\times10^{-3}\ m^2/FIN)$

$\eta \rightarrow$ FIGURE 8-59 (WEB PAGE)

$\xi = (L + \tfrac{1}{4}D)\sqrt{2h/kD}$

$= (3\times10^{-2} + (\tfrac{1}{4})(0.25\times10^{-2}))\sqrt{(2)(35)/(237)(0.25\times10^{-2})}$

$= 0.33$

$\therefore \eta = 0.88$ (APPROX.)

$\therefore q = (35)(0.865 + (0.88)(6.63))(70)$

$= 16413.5$ WATTS (WOW!).

QUESTION 3 → FIN EFFECTIVENESS, ε_{FIN}

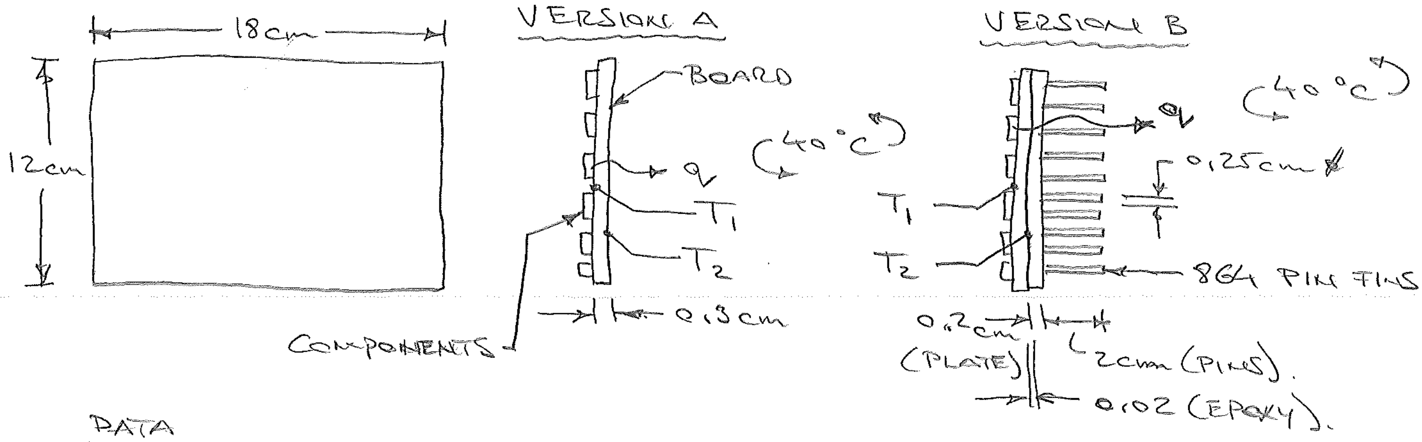
$$\varepsilon_{FIN} = \frac{\text{HEAT TRANSFER FROM THE FIN / BASE SYSTEM}}{\text{HEAT TRANSFER FROM THE BASE ONLY (NO FINS)}} = \frac{q_{FIN}}{q_{NO\,FIN}}$$

$$= \frac{q_{FIN}}{h A_{base} \theta_b}$$

$$= \frac{16413.5}{(35)(1\times1)(70)}$$

$$\varepsilon_{FIN} = 6.7$$

QUESTION 4.



DATA

HEAT: $q = 0.04\ W/\text{chip} \times 80\ \text{chips} = 3.2\ \text{WATTS}$.

THERMAL: BOARD → $k = 20\ W/m\cdot°C$

MEDIUM → $h = 50\ W/m^2\cdot C$

ALUMINIUM → $k = 237\ W/m\cdot°C$

EPOXY → $k = 1.8\ W/m\cdot°C$

CALCULATIONS

a) BOARD ONLY.

$$q = hA(T_2 - T_\infty) \qquad A = A_{BASE} = (12\times10^{-2})(18\times10^{-2}) = 0.0216\ m^2$$

$$\therefore T_2 = \frac{q}{hA} + T_\infty$$

$$= \frac{3.2}{(50)(0.0216)} + 40$$

$$= 42.96\,°C$$

4a CONTINUED

ALSO $q = \frac{kA}{\Delta x}(T_1 - T_2) = \frac{(T_1 - T_2)}{R}$

$\therefore T_1 = qR + T_2$

$R = \frac{\Delta x}{kA} = \frac{0.3 \times 10^{-2}}{(20)(0.0216)}$

$R = 0.007$

So $T_1 = (3.2)(0.007) + 42.96$

$= 42.98\ °C$ ($T_1 \simeq T_2$ IT SEEMS).

4b) PIN FIN.

RECALL: $q = h(A_b + \eta_f A_f)\theta_b$

$= h(A_b + \eta_f A_f)(T_2 - T_\infty)$

$\therefore T_2 = \frac{q}{h(A_b + \eta_f A_f)} + T_\infty$

$A_b = [(12\times10^{-2})(18\times10^{-2})] - 864\left(\frac{\pi(0.25\times10^{-2})^2}{4}\right)$

$= 0.017\ m^2$

FIG 8-59 (WEB PAGE)

$A_f = [\pi D(L + (\frac{1}{4})D)]n = [\pi(0.25\times10^{-2})(2\times10^{-2}) + (\frac{1}{4})(0.25\times10^{-2})]864$

$= 0.676\ m^2$

$\xi = (L + (\frac{1}{4})D)\sqrt{2h/kD} = [(2\times10^{-2}) + (\frac{1}{4})(0.25\times10^{-2})]$

$\times \sqrt{(2)(50)/(237)(0.25\times10^{-2})}$

$= 0.27$

$\therefore \eta_{FIN} = 0.91$ (FIGURE 8-59, WEB PAGE).

So $T_2 = \frac{(3.2)}{(50)(0.017 + (0.91)(0.676))} + 40$

$= 40.1\ °C$

AND $T_1 = qR + T_2$

$= (3.2)(0.007) + 40.1$

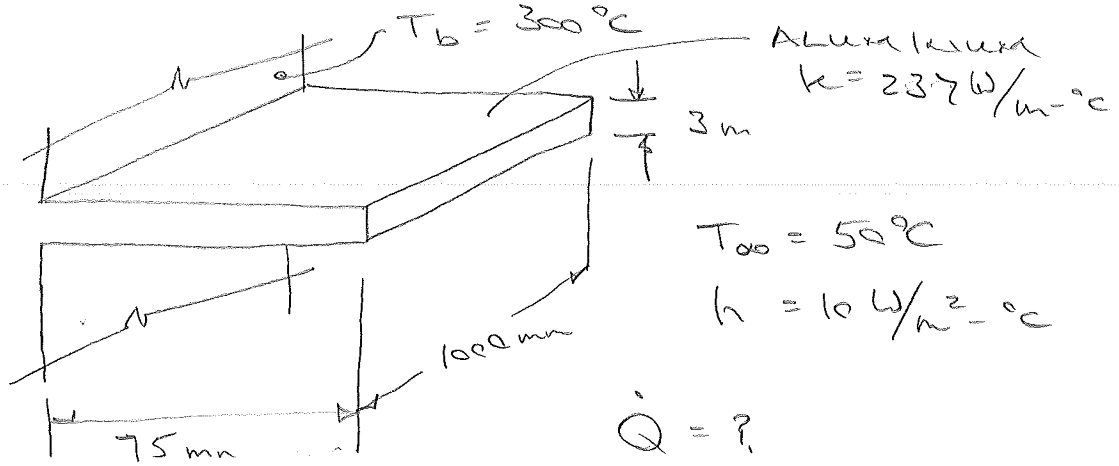
$= 40.122\ °C$

NOTE:

① THE PIN FIN IS NOT NEEDED AND THUS IS A TOTAL WASTE OF MONEY!

② THE SPECIAL COPPER FILLED BOARD IS A USELESS COST!!

EXAMPLE: FIN COOLING



$T_\infty = 50°C$

$h = 10 W/m^2\text{-}°C$

$\dot{Q} = ?$

$$A_{FIN} = 2w\left(L + \tfrac{1}{2}t\right)$$
$$= 2(1)\left(0.075 + \tfrac{1}{2}(0.003)\right)$$
$$= 0.153 \text{ m}$$

$$\xi = \left(L + \tfrac{1}{2}t\right)\sqrt{h/kt}$$
$$= \left(0.075 + \tfrac{1}{2}(0.003)\right)\sqrt{10/(237)(0.003)}$$
$$= 0.287$$

$\therefore \eta \simeq 0.9$

so
$$\dot{Q}_{FIN} = \eta\, h\, A_{FIN}\left(T_b - T_\infty\right)$$
$$= (0.9)(10)(0.153)(300 - 50)$$
$$= 344.25 \text{ W}$$